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Patent Expiration, Product Concentration, and Glyphosate Use: A Tale of Unexpected Consequences

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PATENTS ARE a powerful tool for asserting intellectual property rights—they offer innovators profitable exclusive rights, thereby providing incentive for critical (and costly) investments in research and development. However, this exclusivity is limited in time. After 20 years (from application), patents expire and generic producers can practice the invention. The enhanced competitiveness of the market typically brings additional benefits to final users. Not much is expected to go wrong when a critical patent on a major product expires—but, as articulated in a recent CARD study (http://bit.ly/CARD19wp588), glyphosate provides an unusual tale.

Glyphosate is the world's most used herbicide. Much of its popularity can be traced to the widespread adoption of genetically engineered glyphosate-tolerant crops. Despite its huge commercial success among US farmers, glyphosate has also stirred some controversy related to the emergence of weed resistance, as well as ongoing litigation for its alleged link to cancer. However, our investigation concerns a narrower point—namely, how changes in the formulation of glyphosate products (increased concentration of its key ingredient) impacted US corn and soybean farmers' glyphosate usage behavior. To perform this investigation, we relied on a large, proprietary farm-

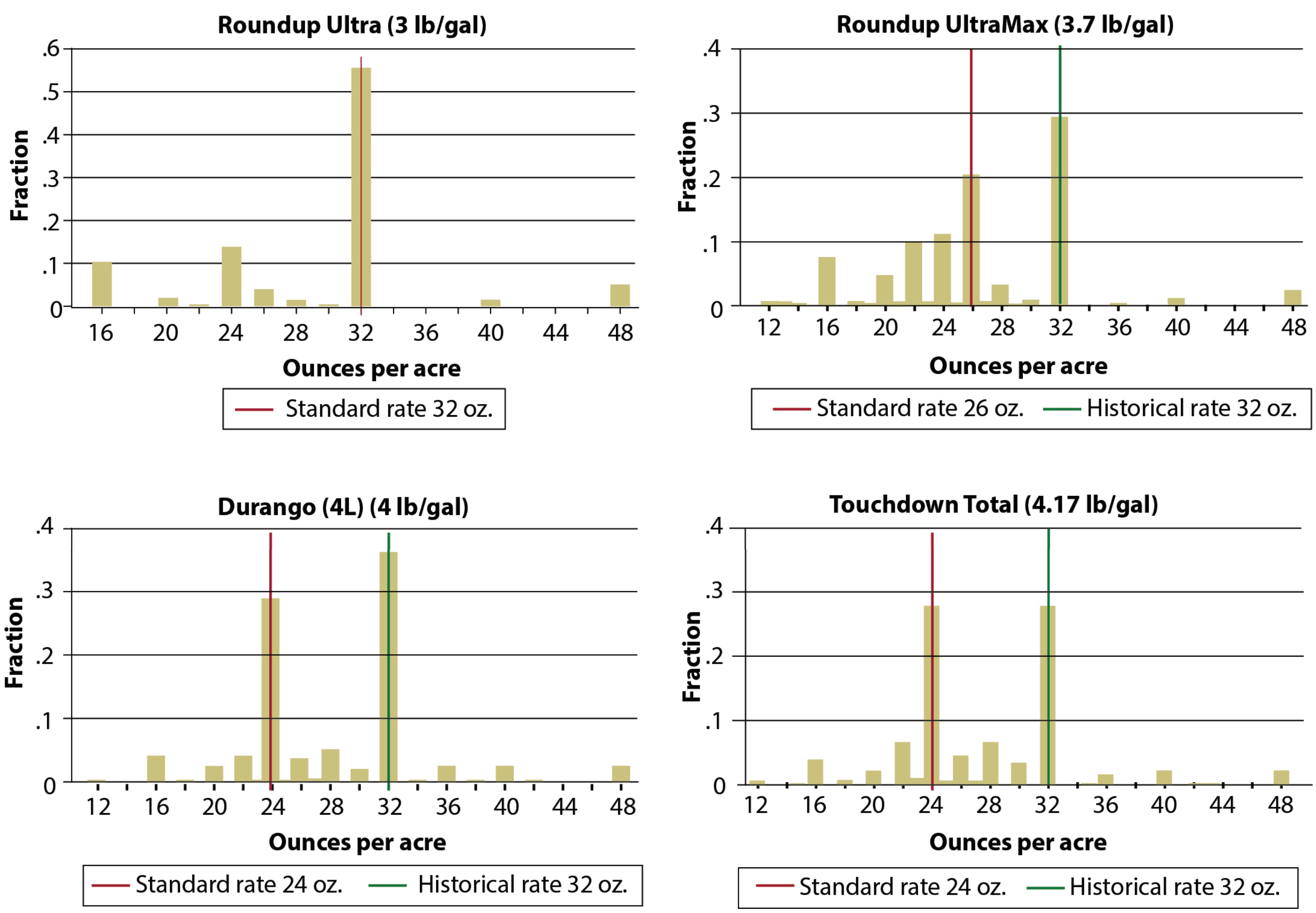

Figure 1. Selected commercial glyphosate product histograms, 1998–2011 [y-axis: fraction of applications; x-axis: application rate (oz/acre)]

Note: Product concentration level in parentheses. The "Standard Rate" is the product-specific rate for the standard field rate of 0.75 lb/acre and the "Historical Rate" is the pre-patent expiration standard rate of 32 oz/acre for 3 lb/gal products.

level dataset of 191,789 glyphosate application decisions made by US corn and soybean farmers from 1998 to 2011.

Prior to 2000, the US glyphosate market was a monopoly. Virtually all farmers purchased one formulation of Monsanto's Roundup, which contained 3 lb/gal of the acid glyphosate in the form of an isopropalymine salt. The standard recommended field dose for a single application of glyphosate was 0.75 lb/acre, which implied a product-specific rate of 32 fl oz/acre with 3 lb/gal products. This is indeed the rate that the majority of farmers used. Following the patent expiration in 2000, new products with higher concentration levels also entered the market (e.g., products with 3.7, 4, and 4.5 lb/gal). As such, the standard product dose was lowered on the labels of these higher concentration products. As farmers adopted higher concentration products, however, a strong pattern emerged—many farmers were applying them at 32 fl oz/acre, the pre-patent expiration standard rate for 3 lb/gal products.

To illustrate this remarkable tendency, Figure 1 shows histograms of application rates for four of the most popular commercial glyphosate products in our data. The red line indicates the product rate for a standard single dose of glyphosate (0.75 lb/acre) for each product and the green line marks the rate of 32 fl oz/acre, the historical product rate for a standard application of 3 lb/gal products. As expected, there was significant clustering at the standard rate for all products. For example, the standard rate for Roundup UltraMax was 26 fl oz/acre, and about 20% of applications were indeed at this rate. However, what is more remarkable is the other clustering, which occurs at the green line, or 32 fl oz/acre. For certain products, this was the most common application rate, despite the fact that the label instructions for these newer products never explicitly suggest 32 fl oz/acre.

What could explain this seemingly anomalous behavior? In addition to old-fashioned confusion, as may arise in more complex environments, we argue that a good part of the story is inertia—farmers relied on *habit*, or rule of thumb, in choosing the application rate when confronted with newer, more concentrated products.

The use of habit and rule of thumb is not unusual in complex decision contexts. Modern crop farming is a technologically intensive business where producers need to manage production, storage, distribution, and marketing, while also dealing with finance, weather, pests, regulations, and other hazards. Successful farming in the face of such complexity leaves latitude for apparent inefficiencies or unintended consequences. One activity that has become increasingly complex is pesticide application. There are hundreds of pesticide products, differing in attributes such as compound, concentration, salt, and surfactants. With so many differences in both attributes and application situations, pesticide products can come with instruction labels exceeding 50 pages in length. As a result, various extension webpages have been written to help farmers navigate the choice and use of hundreds of different pesticide products. (Indeed, recently, herbicide label complexity has been cited as a source of spray drift by farmers who applied Dicamba herbicide to newly-released Dicamba resistant soybeans.)

It is important to emphasize our study does not suggest that farmers should never use higher herbicide application rates. Some circumstances may indeed warrant higher rates (for example, high weed pressure). Rather, what the data reveals is that some producers used higher doses with higher concentration products at disproportionate rates by focusing on the old 32 fl oz/acre application rate.

As with any statistical analysis, it is important to consider the possibility that other factors may have contributed to the observed behavior. The model of the study does, in fact, establish that falling glyphosate prices (because of increased market competitiveness) also promoted glyphosate use. Still, having accounted for the contribution of other factors, such as prices and farmer demographics, we find that a significant component attributable to the concentration effect remains—other things equal, when farmers used a more concentrated product, their overall use of glyphosate increased.

How much of a difference did the "concentration effect" make on the overall use of glyphosate? To answer this, we develop a carefully structured counterfactual analysis centered on having identified a set of "rationally attentive farmers" who used the correct dosage with more concentrated glyphosate products early on. Our conclusion is that, had all farmers behaved as rationally attentive farmers, US corn and soybean farmers would have used 4.4% less glyphosate from 2003 to 2011, saving an average of $59 million per year.

These findings have some broader implications for producers, extension programs, and regulation. First, they imply an opportunity to reduce the use of glyphosate, and potentially weed-tolerance selection pressure, without losses in efficiency. In addition to increasing profitability, such a reduction in herbicide use would mitigate any adverse effects that the chemical has on ecological and human health. Our work also suggests an

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